Bubbles & Turbulence in the Ocean Surface Layer & Topographic Interactions in Coastal Waters

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LONG TERM GOAL

We have two long term goals relating to this project: (i) To determine processes responsible for vertical transfer of heat, mass and momentum across the near surface of the ocean, including the role of bubbles in mediating and serving as tracers of such processes; (ii) To elucidate the fluid dynamical processes associated with stratified flow over topography and its oceanographic implications for circulation in continental shelf and coastal waters.

OBJECTIVES

The key scientific objectives are (i) to identify the processes determining bubble distributions in the upper few meters of the wind driven ocean surface layer, and their relationship to wave breaking, turbulence and the effects of buoyancy, gas dissolution and advection by coherent circulation; (ii) to determine the mechanisms responsible for establishment of stratified flow over topography, in particular the role of small scale instability and entrainment, the consequences of variations in both barotropic forcing and the implicit variations in baroclinic forcing due to changes in stratification brought about by small scale mixing, and finally, solitary wave generation.

APPROACH

For the bubble data we are examining two primary data sets: that acquired from a fixed mooring in the Gulf of Mexico and a shorter term deployment from a cruise off the west coast of Canada. In both cases, bubble size distributions were measured, along with other characteristics of the surface layer. Our approach has involved determination of the key factors we identify as crucial to an understanding of near surface turbulence and mixing in a wind driven sea: wave breaking frequency, bubble injection and Langmuir circulation. The use of the bubble size distribution as tracers of these effects depends on knowing the initial size distribution, and having a suitable model of bubble cloud evolution including effects of gas dissolution and buoyancy. The initial distribution appears to approximate a power law over a significant radius range, providing added motivation for modeling bubble break-up. Subsequent evolution is described with a Lagrangian model that allows for individual dissolution and buoyancy. We use the results to interpret our observations.

For our studies of stratified flow over topography, our approach has been to use data sets acquired in a coastal inlet, in which the velocity and density structure provide insight on the initiation and

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subsequent establishment of the flow response. Our interpretation takes advantage of solutions to the nonlinear hydrostatic equations for layered flow, which turn out to be appropriate for most of the conditions encountered. Further exploration of unsteady and non-hydrostatic aspects of the observations lead to insights on the transition between different internal hydraulic states and the generation of internal solitary waves.

WORK COMPLETED

With respect to our work on upper ocean processes, a theoretical investigation of bubble break-up has been completed. We have completed our research on thermal measurements of turbulent transport near the ocean surface. We have completed our analysis of wave breaking frequency. We have implemented a Monte-Carlo simulation of bubbles injected beneath breaking waves, suitable for analysis of existing bubble size distribution data sets and applied this to the task of reconciling our bubble size distribution observations with expected effects of buoyancy, gas dissolution and advection by Langmuir circulation. An analysis of fine scale temperature and bubble measurements has been carried out to determine the significance of torques due to Langmuir circulation induced anomalies in these properties compared to the corresponding torque associated with the interaction between Stokes drift and wind shear.

We have completed our analysis of the generation of internal solitary waves over topography and of the role of small scale instability and entrainment in flow establishment. This work has been extended to consider he implications of strong barotropic forcing, in which control is lost at the sill crest.

RESULTS

We have shown that surface heat loss produces measurable small scale thermal gradients near the ocean surface (Gemmrich & Farmer, 1999a), that these are modulated by Langmuir circulation, and that they can be explained with an advective-diffusive model of the near surface circulation. The implicit roughness length of the ocean surface turns out to be smaller than we would expect on the basis of available turbulence data. We have also been able to show (Figure 1) that by scaling wave breaking in terms of the energy input into the wave field, we are able to collapse diverse data sets, including both fetch limited and open ocean results (Gemmrich & Farmer, 1999b). In a theoretical study of bubble break up we have shown that dimensional analysis leads to predictions of power law bubble size distributions which have some similarity to observations, but we must invoke turbulent intermittency in order to explain the details (Garrett, Li & Farmer, 1999). Our analysis of mixed layer temperature structure reveals well defined vertical coherence consistence with Langmuir circulation when the mixed layer is shallow (Figure 2), becoming less well defined as the mixed layer deepens (Farmer, Vagle & Li, 1999b). Our results show that compared to the torque induced by the interaction of Stokes drift and wind shear, the corresponding torque due to bubble distributions and thermal buoyancy organised by Langmuir circulation is small. In our studies of stratified flow over topography we have demonstrated the role of small scale instability and entrainment in flow establishment (Farmer & Armi, 1999b), and have been able to identify in our observations and explain theoretically the process by which strong forcing leads to a transition from a state in which the flow is controlled above the crest of the topography, to a state in which control above the crest is lost. In this latter state, the streamline bifurcation is pushed downstream of the crest and changes in the barotropic forcing lead simply to changes in its resulting location.

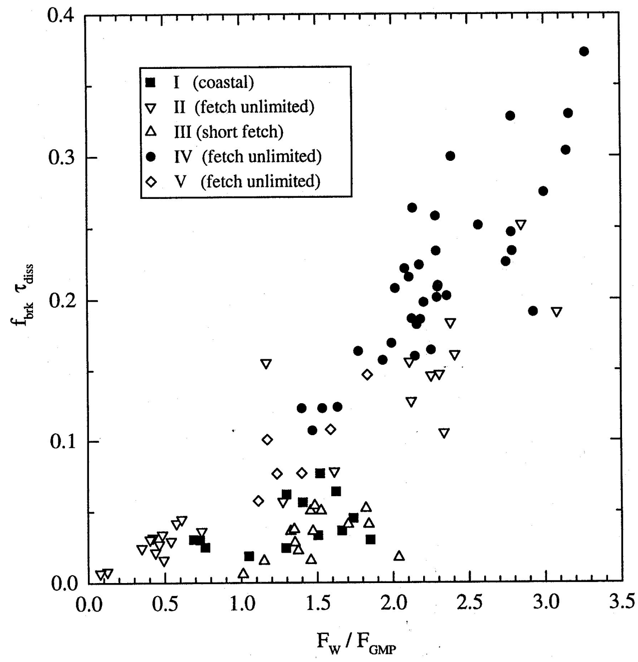

Figure 1. Normalized wave breaking frequency as function of scaled energy input into the wave field. The normalization collapses diverse data sets from fetch limited and open ocean conditions (from Gemmrich & Farmer, 1999b)

An interesting result has been the recognition that topographic flows of the type we have examined are subject not only to barotropic forcing, but also to certain baroclinic effects which can have a profound influence on the flow response. Specifically, the density difference across the streamline bifurcation can change with time as small scale instability leads to entrainment into the slowly moving layer. As the density difference decreases, the combination of barotropic and baroclinic effects can increase, even as the barotropic forcing declines. We have also identified the potential role of shear instability in solitary wave generation and shown how solitary waves can be trapped over topography (Farmer & Armi, 1999a).

IMPACT/APPLICATION

Near surface structure helps to determine vertical transport of key oceanographic variables such as heat, mass and momentum. Bubble distributions in particular, provide clues as to the character of wave breaking, turbulence and upper ocean circulation, as well as playing a more direct role in air sea transport of gases and influencing the upper ocean acoustic environment.Topography exercises a strong influence on coastal circulation through mixing of water masses and through hydrodynamic drag. Small scale instability and boundary layer separation modify the way in which topographically forced flows behave under varying barotropic forcing and consequently modify the larger scale oceanographic response.

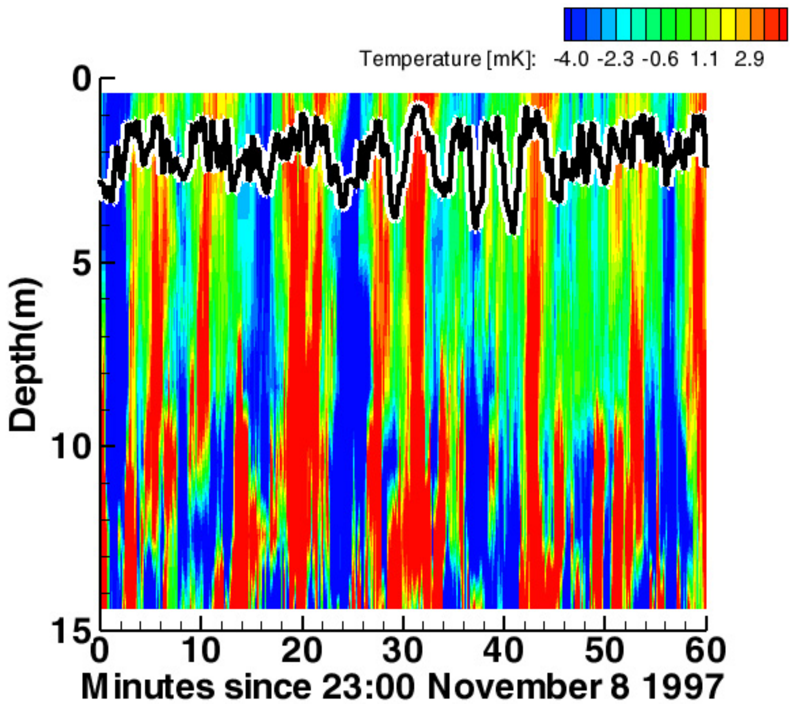

Figure 2: Fine scale temperature fluctuations measured in the surface mixed layer (depth ~10m) illustrating the strong vertical coherence of Langmuir circulation. Bubble penetration (black line) is greatest in cooler water. (from Farmer, Vagle & Li, 1999b)

TRANSITIONS

Bubble measurement technology and analytical approaches developed under this project, are finding application in the study of effects on the acoustic environment. Specifically, the recent ONR funded Acoustic Communications project has involved field studies of bubble distributions in the surf zone, as well as model analysis of the evolution of bubble clouds and their influence on acoustic propagation.

Our work on stratified flow over topography has motivated theoretical analysis of stratified flow problems by two investigators: Patrick Cummins at IOS and Yakov Anassief at Memorial University. In both cases, the investigators have used numerical models in an attempt to simulate results from our published measurements, providing added insights on the problem of flow establishment from rest.

PUBLICATIONS

Papers:

Farmer, D. and Armi, L., 1999. The generation and trapping of solitary waves over topography. ***Science,*** 283, 5398, 188-190.

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The 1998 WHO/IOS/ONR Internal Solitary Wave Workshop: Contributed Papers, Edited by Tim Duda and David Farmer, July 1999, Technical Report 251pp.